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Article

Evaluation of vortex tube orifice percentage in terms of sediment trap efficiency in laboratory conditions

Evaluación del porcentaje de apertura de orificio del tubo vórtice respecto de la eficiencia de retención de sedimentos en condiciones de laboratorio

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Abstract

Unfamiliarity with sedimentation problems in the basin has delayed a large number of projects in development, resulting in high costs. Different methods are used to prevent sediment from entering, which is transported by rivers in the form of bed load, and flows into the basin. These methods, which use vortex tubes, include increasing soil levels in the basin, building earthen walls or installing submerged panels to eliminate sediment from the inlets, and sediment traps, the use of vortex tubes. Since many variables are effective for retaining sedimentation and water loss with the vortex tube, the objective of this study was to evaluate the performance of vortex tubes *in vitro*, with a controlled discharge, and with four orifice widths/tube diameter (*t/d*) proportions (0.15, 0.20, 0.25, and 3.0), and a 45% angle with different discharges. The results showed that 43.2 kg of sediment were retained with a 0.25 *t/d*, which was equivalent to 84.16% of the total sedimentation that entered the system; and 36.02 kg of sediment were retained with a 0.3 *t/d*, which was equivalent to 84.43% of the total sedimentation that entered the system. With an increase in *t/d*, the retention of sediments will increase. For this index, the best option was

t/d = 03. Nevertheless, if the supply of water in a region is extremely important and water is scarce, the discharge diverted with a *t/d* of 0.3 would be 13.88%, and 11.62% with a *t/d* of 0.25. Then the better option will be *t/d* = 0.25

Keywords: Vortex tube, trapping, orifice percentage, sediment, the Froude number.

Resumen

La falta de familiaridad con los problemas de sedimentación en la cuenca ha demorado una gran cantidad de proyectos durante su desarrollo, trayendo consigo altos costos. Por lo general se utiliza para prevenir la entrada de sedimento que se desplaza como carga de lecho en las corrientes y ríos que se dirigen hacia la cuenca. Diversos métodos, como el aumento del nivel del lecho de la cuenca, el montaje de la pared del suelo o placas sumergidas para eliminar el sedimento de la entrada, y el desarenador (pileta de sedimentación), se emplean en la utilización del tubo vórtice. Dado que muchas variables son efectivas en la retención de sedimentación y la pérdida de agua del tubo vórtice, el objetivo de este estudio fue evaluar el rendimiento del tubo vórtice *in vitro* en una descarga controlada con cuatro proporciones de ancho de la hendidura del tubo al diámetro (*t*/*d*), 0.15, 0.20, 0.25 y 3.0 en un ángulo de 45 grados con diferentes descargas. Los resultados demostraron que en la proporción *t*/*d* = 0.25, se retuvo un total de 43.2 kg de sedimento, lo cual equivale a 84.16% del total de sedimentación ingresado al sistema; y en proporción *t*/*d* = 0.3, 36.02 kg de sedimentos fueron retenidos, en equivalencia a 84.43% del total de sedimentos ingresados al sistema. Con un incremento del porcentaje *t*/*d*, el proceso de retención de sedimento tendrá una tendencia creciente. En este índice, la mejor opción resulta ser *t*/*d* = 0.3. No obstante, si el suministro de agua es de extrema importancia en una región y existe escasez de agua, dado que en *t*/*d* = 0.3, el desvío de descarga es de un 13.88% y en *t*/*d* = 0.25, el desvío de descarga resulta ser de un 11.62%; una mejor opción será *t*/*d* = 0.25.

Palabras clave: tubo vórtice, retención, porcentaje de orificio, sedimento, el número de Froude.

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Introduction

Normally, attempts are made to prevent sediments from entering and being transported by river beds in a basin. The methods include increasing soil levels in the basin, building earthen walls or installing submerged panels to eliminate sediment from the openings to the basin, sediment ponds, and the use of a vortex tube.

Nevertheless, sediments enter the bed when a basin floods, even with the design of these structures, and due to the fixed number of these structures and the varying hydraulic conditions, especially when floods have a large volume of sediments.

Therefore, simple and inexpensive structures need to be designed that can separate sediment from the bed and direct it to the river.

If the sediments that enter the basin are not taken into account, they will be transported to the installation and produce many problems as a result of sediment transport, or be deposited in different areas.

The transportable sediment depends largely on the amount of sediment in the catchment area and the characteristics of the river. If the flow in parts of the transmission system is low, especially in systems with gravitational water, such that the flow of water cannot maintain the transferred material in a suspended state, then additional deposits settle in the channels. This action begins in the basin and gradually extends throughout the system. Depending on the slope of the channels, they can collapse, and with an increase in the channel bottom, their free height decreases and the ability to supply water will decrease. Therefore, it is very important to control the entrance of sediments into a basin.

A new method for controlling sedimentation is the use of a vortex tube in rivers, which is inexpensive because it is smaller than conventional rectangular sediment ponds and can be continually used.

This method of controlling sediments is based on the use of rotational force and the gravity of the sediment particles. This type of sediment is used in cases where the bed load concentration is high, for the continuous flushing of sediments. The main part consists of a tube or horizontal conduit embedded inside or under the channel, and the sediments near the bottom of the channel are transferred outside. This flow then discharges into a drain or drainage basin. Figure 1 shows a layout of a vortex tube.

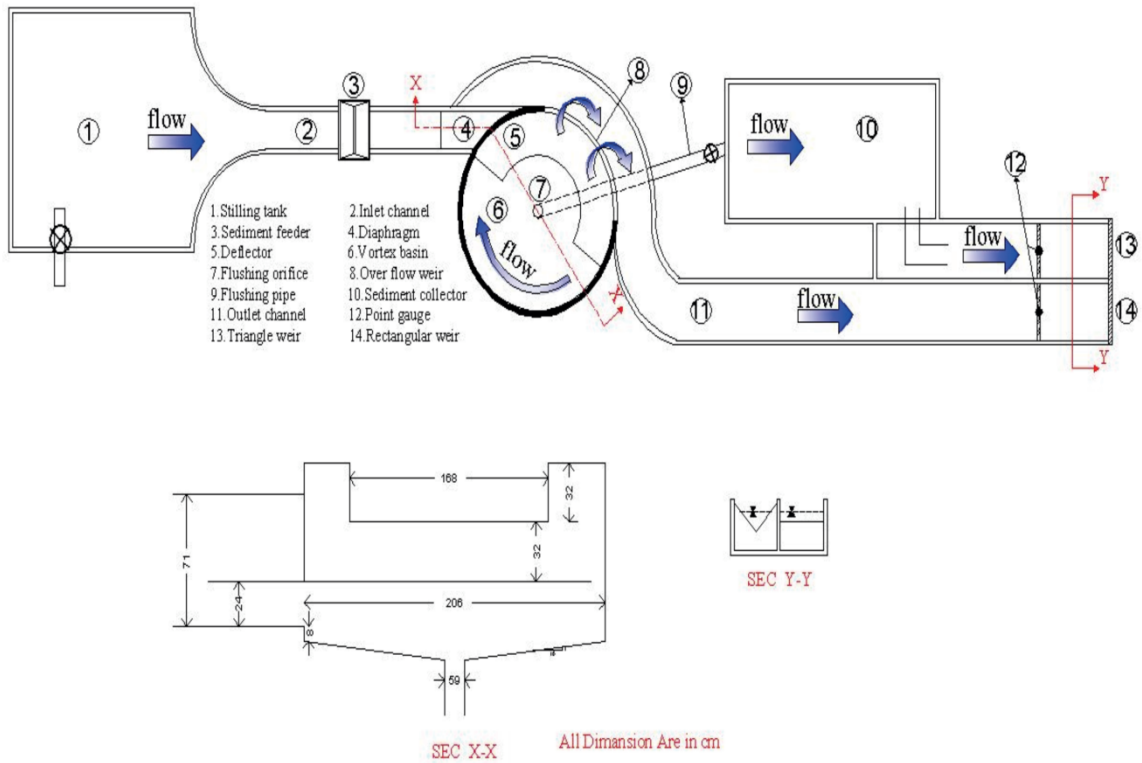

Figure 1. Layout of a vortex tube

The vortex tube can be placed near the drain or at a sufficient distance from the base of the installation, where the distribution of the sediments is at an equilibrium.

The idea of using a flow tube in particular environmental conditions has advantages and disadvantages in comparison with other sedimentation control methods, since it works in a completely controlled section. The water enters the structure at an angle and creates a strong vortex at the tube shaft, generating a vortex flow. The flow inside the tube is controlled by a valve and then empties into a channel. The vortex tube is highly effective when the suspended load is low and the soil load is significant.

Nevertheless, good performance has been reported even when the suspended load is high. Parshall (1951) can be considered the founder of this project. Blench (1952) indicated that the vortex tube is used for large channels with a large flow capacity of 280 m^3/s (1 000 $feet^3/s$). Robinson (1962) and Ahmed (1962) reported a Froude number for the channel ($0.8\ v/\sqrt{gh}$). Parshall (1952) reported that the lowest efficiency occurs when the Froude number is 1. Atkinson (1994) conducted an

investigation of the tube angle (θ) and the tube to pipe ratio (*t/d*), which showed that tangential velocity inside the tube is at its maximum when the tube is at 90 degrees or more in relation to the flow direction and *t/d* is low (roughly 0.3 or less).

Nickmehr Farhoudi, and Omid (2010) examined the parameters that affect the flow of the vortex condenser tube, such as tangential velocity, closing speed, and energy loss, with controlled and uncontrolled (free) discharge from irrigation canals. Their investigation included four inlet widths and tube diameters (*t/d*): 0.15, 0.2, 0.25, and 0.3, which was affected by four controlled discharge rates of 2.5%, 5%, 5/7%, and 10%, respectively. The results showed that when the ratio between the inlet space where the sediments entered and the diameter of the tube was 0.15, the effective parameters for trapping the sediments were under controlled conditions and were not controlled under optimal conditions. Muazzen and Shafaei-Bajestan (2003) attempted to investigate the effect of the diameter and the angle of the tube in different hydraulic conditions. Their results showed that the trapping efficiency depended on the flow, and therefore, when increasing the Froude number, the trapping efficiency first increased and then decreased. The maximum trapping efficiency was 0.6. The water loss also decreased when the Froude number increased, with a greater loss (8.5%) when the Froude number was 0.2, and less of a loss (4%) when it was 0.91. The water loss rate was 0.6 to 0.8, up to a maximum of 7%.

Given that many variables affect the sediment trapping rate and the water loss rate in a vortex tube, the purpose of this study was to evaluate the function of the vortex tube under laboratory conditions, with controlled flow, and four proportions of distance between the tube and the tube diameter (*t/d*), 15/0, 20/0, 0.25, and 0.3, at a 45° angle with different flows.

Materials and methods

The experiments were carried out at the laboratory of the Islámica Azad University, Ahvaz, located in Chanibe, to examine the effect of the ratio of the vortex tube orifice versus the tube diameter (*t/d*) on the efficiency of trapping sediments, with four different *t/d* and four different flow velocities, using a 13 m-long canal with a width of 50 cm

and a depth of 60 cm. To conduct the hydraulic tests, first, the water flow was completely cleanded in order to ensure that the water flow in the channel was transparent and visible. The reservoir was then emptied using a water tank. After ventilating, the main canal was lit and after a time —and to ensure that the flow had filled as of the air deposit in the laboratory— the valve opens the canal inlet to permit the water to enter the main channel. The inlet valve opened enough so as to provide the desired flow. After a period of flow, a flow was introduced through a 13 m canal in the basin, in the bottom, and was measured with a triangular weir with a 60° angle. The discharge from the tube, which ran though a 3.5 m canal to an earth deposit, was measured with a triangular weir with a 90° angle. Figure 2 shows a 90° weir.

Figure 2. Measurement of the flow discharged from the vortex tube with a 90° weir.

The sum of the two flows previously mentioned is the flow velocity in the canal. Nevertheless, if the flow velocities differ, the inlet valve will open and close so that they are the same as the desired flow. Using measuring sticks installed in the body of the canal and under the same conditions, with a stable flow, the flow depth was again measured upstream, downstream, at the inlets and outlets, and descending from the ventral tube. As well as the flow of the canal and the flow from the inlet. The millimeter measuring stick was retrieved.

Given the limitations of the laboratory and the discharge from the pump, the experiments were performed with a maximum flow of 20 l/s and a minimum of 10 l/s 10. To examine the effect of the vortex tube orifice/tube diameter proportion (*t/d*) on the efficiency of the sediment trapping, four inlet flow velocities were used (10, 13, 15, and 20 l/s) with the *t/d* proportions of 0.15, 0.25, and 0.3. The diversion flow and

depth of the water were planned and measured at the points measured previously. To reduce at the inlet the perturbation of the flow from the pump to the canal, a lattice tube was used to diminish the energy of the water. According to the recommendation by Radkoviwatma (1983), to prevent the formation of ripples, the diameter of the particles must be 0.7 millimeters larger. With roughly 1 millimeter, the standard deviation was 1/3. The gradient and specific gravity were obtained, and a 3 cm-thick layer was used to conduct the experiments.

The granulometric curve is shown in Figure 3, and the laboratory process in Figure 4.

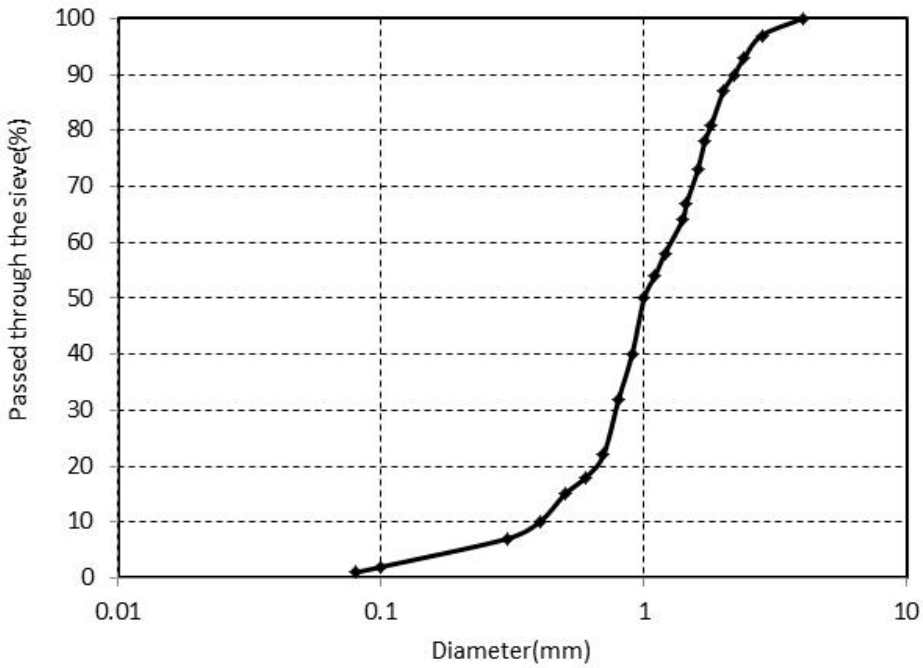

Figure 3. Granulometric curve.

Figure 4. Laboratory process for obtaining the granulometric curve.

To measure the amount of sediments, a lattice plate was used, whose diameter was less than the diameter of the grid (Figure 5). The dry sediments were weighed with a digital scale under laboratory conditions.

Figure 5. Flow discharge tube, diversion sediment and collection of sediment.

To measure the transport of sediments that were not trapped, at the end of each experiment, the sediments deposited at the bottom of the main canal and in the traps installed in the system were collected, and the dry weights were calculated using a digital scale under laboratory conditions.

Results and discussion

In general, the experiments measured the diversion flow rate, the discharge flow rate, and the total flow in liters per second, as well as the sediments diverted (trapped sediment), the inlet to the system, and the residual sediments, in kilograms. The results are shown in Tables 1, 2, 3, and 4.

Table 1. Flow and sediment results for (*t/d*) equal to 0.15. *Fr* = Froude number, *Qi* = diversion discharge, *Qo* = final discharge; *Qt* = total discharge; *Qsi* = weight of sediment diverted; *Qso* = final weight of sediment; *Qst* = total sediments; *Te*% = percentage of sediments diverted, and *we*% = percentage weight of water.

Row	***Fr***	***Qi* (l/s)**	***Qo* (l/s)**	***Qt* (l/s)**	***Qsi* (kg)**	***Qso* (kg)**	***Qst* (kg)**	***Te%***	***we%***
1	0.43	0.985	9.15	10	3.76	2.505	6.265	60.02	9.85
2	0.56	1.248	11.752	13	5.25	2.315	7.565	69.4	9.6
3	0.65	1.44	13.56	15	10.84	1.64	12.48	86.86	9.6
4	0.87	1.476	18.524	20	7.565	2.165	9.73	77.75	7.38
Average								73.51	9.11

Table 2. Flow and sediment results for (*t/d*) equal to 0/2. *Fr* = Froude number, *Qi* = diversion discharge, *Qo* = final discharge; *Qt* = total discharge; *Qsi* = weight of sediment diverted; *Qso* = final weight of sediment; *Qst* = total sediments; *Te*% = percentage of sediments diverted, and *we*% = percentage weight of water.

Row	***Fr***	***Qi* (l/s)**	***Qo* (l/s)**	***Qt* (l/s)**	***Qsi* (kg)**	***Qso* (kg)**	***Qst* (kg)**	***Te%***	***we%***
1	0.43	1.49	8.51	10	8.6	1.65	10.25	83.9	14.9

2	0.56	1.51	11.49	13	10.92	2.05	12.97	84.19	11.62
3	0.65	1.54	13.46	15	7.5	1.1	8.6	87.21	10.3
4	0.87	1.56	18.44	20	12.1	3.4	15.5	78.06	7.8
Average								83.34	11.15

Table 3. Flow and sediment results for (*t/d*) equal to 0.25. *Fr* = Froude number, *Qi* = diversion discharge, *Qo* = final discharge; *Qt* = total discharge; *Qsi* = weight of sediment diverted; *Qso* = final weight of sediment; *Qst* = total sediments; *Te*% = percentage of sediments diverted, and *we*% = percentage weight of water.

Row	***Fr***	***Qi* (l/s)**	***Qo* (l/s)**	***Qt* (l/s)**	***Qsi* (kg)**	***Qso* (kg)**	***Qst* (kg)**	***Te%***	***we%***
1	0.43	1.55	8.45	10	11.9	2.6	14.5	82.07	15.5
2	0.56	1.57	11.43	13	10.8	1.5	12.3	87.8	12.08
3	0.65	1.6	13.33	15	9.8	0.8	10.6	92.45	10.7
4	0.87	1.65	17.35	20	10.7	3.7	14.4	74.31	8.25
Average								84.16	11.62

Table 4. Flow and sediment results for (*t/d*) equal to 0.30. *Fr* = Froude number, *Qi* = diversion discharge, *Qo* = final discharge; *Qt* = total discharge; *Qsi* = weight of sediment diverted; *Qso* = final weight of sediment; *Qst* = total sediments; *Te*% = percentage of sediments diverted, and *we*% = percentage weight of water.

Row	***Fr***	***Qi* (l/s)**	***Qo* (l/s)**	***Qt* (l/s)**	***Qsi* (kg)**	***Qso* (kg)**	***Qst* (kg)**	***Te%***	***we%***
1	0.43	1.58	8.42	10	6.71	1.16	7.87	85.26	15.8
2	0.56	1.872	11.128	13	9.42	1.48	10.9	88.42	14.45
3	0.65	1.968	13.03	15	11.11	1.45	12.56	88.46	13.1
4	0.87	2.43	17.57	20	7.78	2.25	10.03	77.57	12.15
Average								84.43	13.88

Indicator of sediment trapping

In the results presented in the above tables, *t/d* = 0.25 and 0.3, respectively. The trapping efficiency and the amount of sediment

diverted were similar, that is, for *t/d* = 0.25, the total sediment trapped was 43.2 kg, which is 16/84% of the total sediment load in the system, and for *t/d* = 0.30, the total sedimented trapped was 0.33 kg, which is 84.43% of the total sediment load in the system. It is a question of accuracy. With the increase in *t/d*, the percentage of precipitation (trapping of sediments) increased. The preferred option for this index is *t/d* = 0.3 (Figure 6).

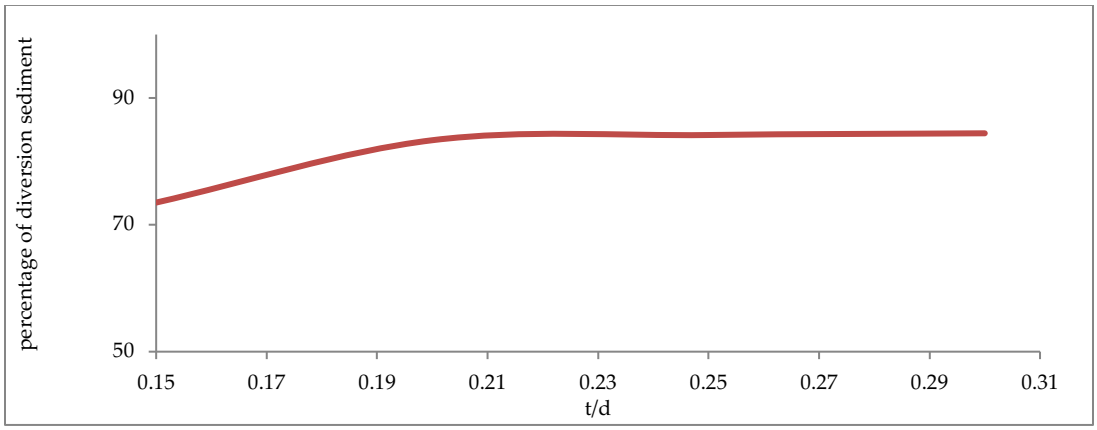

Figure 6. Effect of *t/d* on the percentage of sediments diverted (Te%)

Diversion flow index

Given the importance of the water supply, one of the criteria used to evaluate the experiments is to determine the amount of water lost. As is known, it takes time to supply water and transport it to the water supply or channel, and therefore the sedimentation method selected should prevent the loss of water as much as possible, and its return to the river. Generally, in a vortex tube system, a certain flow amount is needed for diversion and the depletion of sediments, which is measured with experiments of the changes in diversion flows in different states.

As seen in Figure 7, with *t/d* = 0.15, roughly 9% of the total flow is diverted and leaves the system, but since with this *t/d* the sedimentation is little compared to other options (73.51% of the sediments), and with *t/d* = 0.25 roughly 11% of the flow is diverted and much more sedimentation occurs (84.14% of the total sediments), then

for this index *t/d* = 0.25 is the best option. Muazzen and Shafaei-Bajestan (2003); Farhoudi, Nikmehr and Omid (2010), and Moradi, Hasonizade, Kashkul, Moosavi-Jahromi and Sedghi (2013) stated that the amount of sediments trapped depends of the flow.

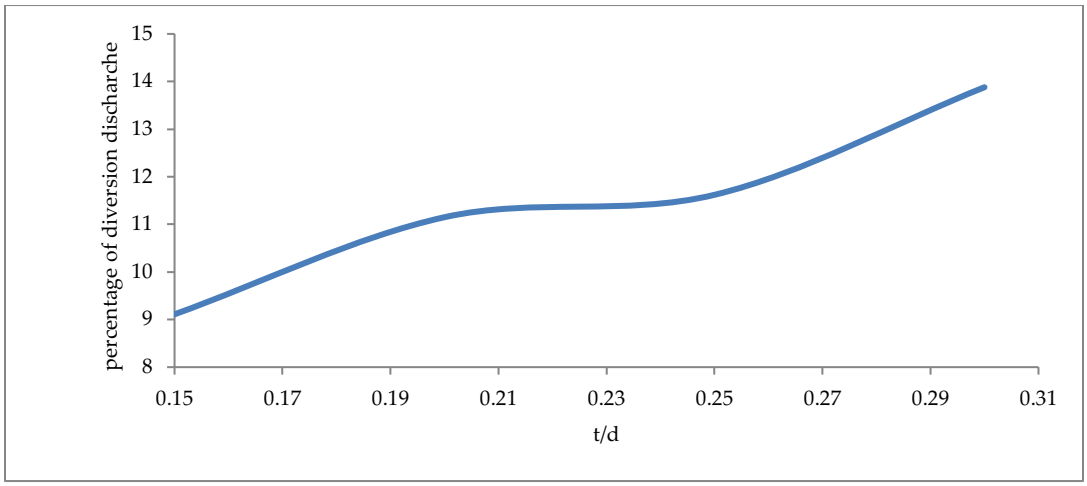

Figure 7. Effect of *t/d* on the diversion flow percentage (*we*%).

Index of sediments entering the system

With the installation of a vortex tube system, over 80% of sediments were trapped and some also entered the water supply or the channels. When examining the amount entering the system with different *t/d*, only 57/15% of the sediments is connected for *t/d* = 0.3, thus this option is suitable.

Conclusion

According to the results of the experiments, when increasing the *t/d*, the percentage of precipitation (sediments trapped) increased, and the amount of water lost is not a limiting factor. In other words, in a region with water scarcity and insufficient water supply, the entering of

sediments into the system is preferable to the water supply, the preferred option is t/d = 0.3. But if the water supply is very important in the area and there water is generally scarce, then the better option is t/d = 0.25.

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